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Book of Abstracts
November 2-5, 1998

Kellie Ann Beall, Editor

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Gaithersburg, Maryland 20899

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EXPERIMENTS ON BUOYANT DIFFUSION FLAME DYNAMICS UNDER CONDITIONS SIMULATING PARTIAL GRAVITY

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Introduction:

Study of buoyant diffusion flame dynamics under different gravity levels is of interest for several reasons. First, the scaling of flame dynamic behavior such as the quasi-periodic flame oscillations is expected to be different at partial low gravity environments. Second, the entrainment characteristics of buoyant diffusion flames at partial gravity conditions are not available to date and this information is needed for fire safety considerations at extraterrestrial settlements currently planned by NASA. So far, small diffusion flame experiments have been performed at microgravity conditions at NASA facilities. These experiments typically have very short durations which preclude experimentation requiring long periods such as those required for steady state fire entrainment measurements. Given these constraints and the need for such experiments, we are conducting laboratory experiments where the buoyant driving force is reduced by tailoring the bulk density differences in earth gravity. This can be accomplished by hydrocarbon flames burning in synthesized oxidizing environments other than air. Helium/oxygen/nitrogen /carbon dioxide mixtures provide conditions of reduced and augmented gravity environments for propane flames as will be shown by the preliminary results obtained so far.

The global buoyancy force per unit volume can be expressed as $(\rho_\infty - \rho_f) * \mathbf{g} / \rho_\infty$ where ρ_∞ is the ambient density, ρ_f is the density in the flamelet regions and $\mathbf{g}$ is the gravitational acceleration. Upon rearranging, the buoyancy force can be written as $\rho_\infty * \mathbf{g} * (1- \rho_f/\rho_\infty)$. The ambient density can be altered by synthesizing ambient atmospheres of different densities. Table 1 shows calculated oxidizing medium densities and the density factor, $\rho_\infty (1- \rho_f/\rho_\infty)$ for air, He/O_2 and CO_2/O_2 mixtures. It is seen that the latter factor can be altered up and down by about 50 % with respect to the air case. While, it has some differences in details from the partial gravity flames burning in air, the global effects such as the large scale flame dynamics and entrainment can be studied at simulated partial gravity conditions by affecting changes in the ambient density instead of the gravitational acceleration. In the following, we present results demonstrating the feasibility of this experiment.

Experimental Set-up:

The set-up for these experiments was similar to those employed in our earlier studies [1]. The experimental facility consists of a concentric nozzle configuration with an inner 2.5 cm dia. fuel nozzle surrounded by a 30 cm dia. coflow nozzle, all being situated under a 1.0 m. dia. hood. The fuel nozzle exit was 3.0 cm further downstream from the exit plane of the coflow nozzle. The fuel nozzle contained a retainer screen above which a bed of glass beads (2.0 mm in dia.) provided the flow resistance for flow uniformity. The coflow nozzle had a honeycomb flow straightener followed by a 20 mesh screen and a bed of glass beads for flow uniformity. Wrapped around the coflow nozzle was a 20 mesh screen to guide the coflow stream upward and prevent the ambient disturbances to adversely affect the flame. The experimental diagnostics included (1) video recordings of the visible flame and (2) detection of small dynamic pressure fluctuations along the flame centerline to determine the oscillation frequencies.

Experimental Results:

A series of visualization experiments were performed to determine the oscillatory behavior of propane diffusion flames. Figure 1 shows the sequence of flame images for a 0.8 kW propane flame burning in air (upper row) as well as the same flame burning in a mixture of helium and oxygen (lower row). The flame burning in air exhibited periodic oscillations characteristic of buoyant diffusion flames with an oscillation frequency of about 10 Hz. This frequency agrees well with the value of 9.5 Hz from the correlation reported in [2]. In the second row of images shown in Fig. 1, the flame oscillations were found to be completely suppressed in a flame burning in a mixture of 75 % helium and 25 % oxygen by volume. The complete elimination of the flame pulsations is attributed to the decrease of buoyancy and resulting changes in the flame dynamics. Figure 2 shows the frequency spectrum of oscillations for the 0.8 kW flames burning in air and helium-oxygen media. While the flames in air exhibit a clear oscillation frequency peak at the fundamental frequency of 10 Hz, the flame burning in helium-oxygen mixture shows no such distinct frequency peaks beyond the background noise level. Similar to our earlier experiments with non-reacting buoyant plumes, there appears to be a threshold of density ratio or buoyancy parameter beyond which the oscillations are completely eliminated. Currently, this transition between steady laminar flames and unsteady, more buoyant oscillatory flames is being studied in our laboratory. Additionally, we are simulating the effects of elevated buoyancy by studying flames burning in CO_2-O_2 mixtures as indicated in Table 1. The presentation will include the results from these ongoing experiments.

References:

1. B. M. Cetegen and K. D. Kasper , Experiments on the Oscillatory Behavior of Buoyant Plumes of Helium and Helium-Air Mixtures, *Physics of Fluids*, **8**(11),pp. 2974-2984 (1996)

2. Cetegen, B. M. and Ahmed, T., "Experiments on the periodic instability of buoyant plumes and pool fires", *Combustion & Flame*, Vol.93, pp.157-184 (1993)

3. Cetegen, B. M., "Behavior of naturally oscillating and periodically forced axisymmetric buoyant plumes of helium and helium-air mixtures", *Physics of Fluids*, Vol. 9. No. 12, p. 3742-3752 (1997)

Table 1: Calculated Densities

Oxidizing Medium	ρ_∞	$\rho_\infty(1-\rho_{fl}/\rho_\infty)$*
Air	1.1601	1.0160
He: 70%, O_2: 30%	0.5038	0.4589
He: 50%, O_2: 50%	0.7313	0.6810
CO_2 : 70%, O_2: 30%	1.6414	1.4442

* Fuel: Propane, ρ_{fl} is the flame zone density for adiabatic combustion, density is in kg/m^3

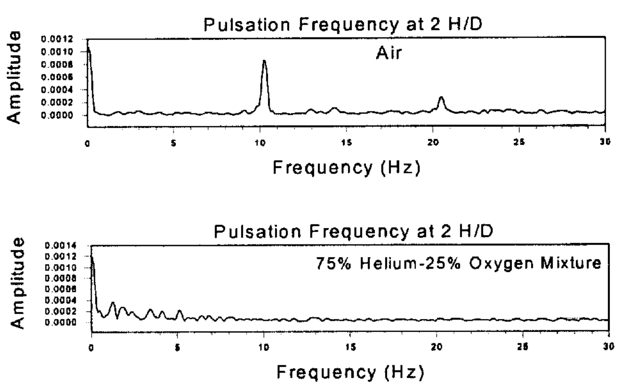

Fig. 2: Frequency spectra of flame oscillations kW propane flame burning in air (top) and in a mixture of helium-oxygen (bottom)

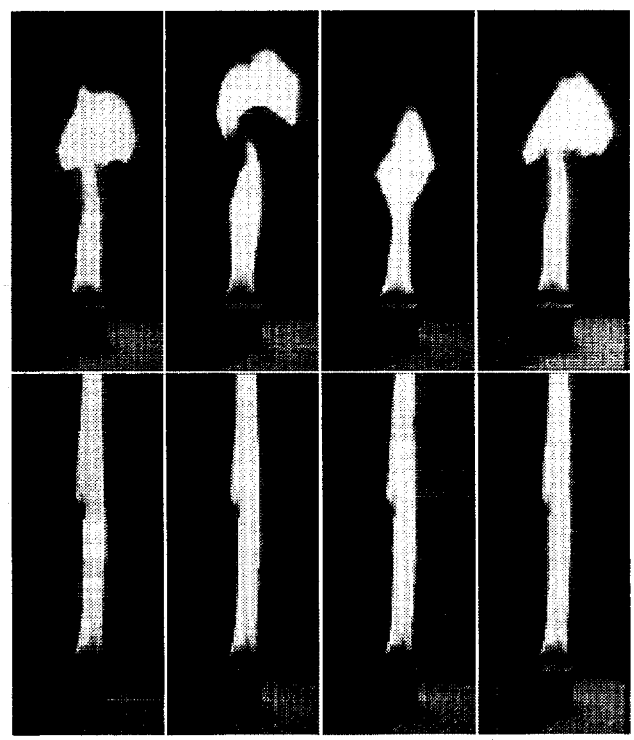

Fig.1: Upper image sequence for 0.8 kW for a 0.8 propane flame in air. Lower sequence for 0.8 kW flame burning in 75 % He-25 % O2 mixture